International Space Station
Design Challenge

CELERE

Capillary Effects on Liquids Exploratory Research Experiments

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Astronaut Mike Fincke conducting the Capillary Flow Experiment (CFE)

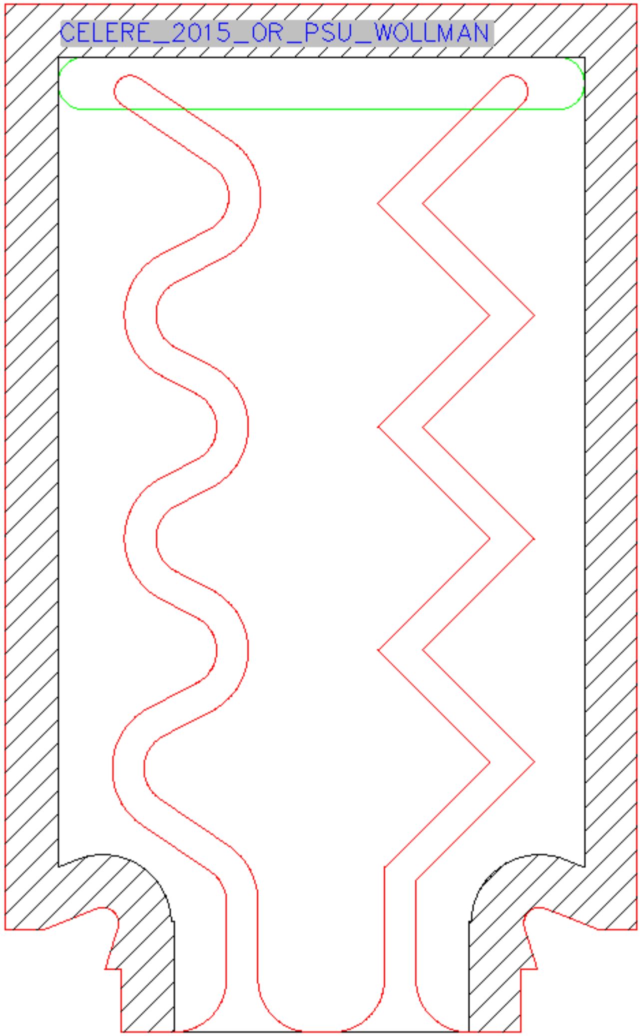
CELERE Design Challenge

- **Enables students to participate in microgravity research like that conducted on the International Space Station (ISS).**

Astronaut Sunita Williams conducting the Capillary Flow Experiment (CFE)

What is it? How does it work? - 1

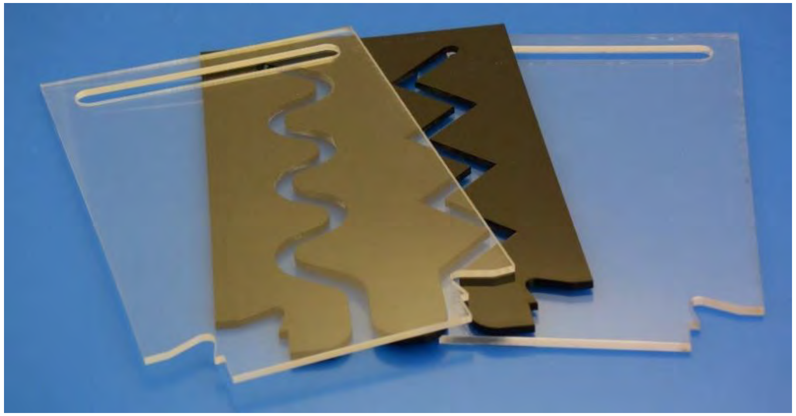
- The design challenge is a joint educational program of NASA and Portland State University (PSU).
- The students participate in microgravity research on capillary action like that conducted on the International Space Station (ISS).
- The students create their own microgravity experiments using Computer-Aided Design (CAD) and a provided drawing template.
  - A tutorial is provided for use with *DraftSight* software (for 2D CAD), which can be downloaded for free.
- The 2D drawing and entry form are submitted to NASA by e-mail.

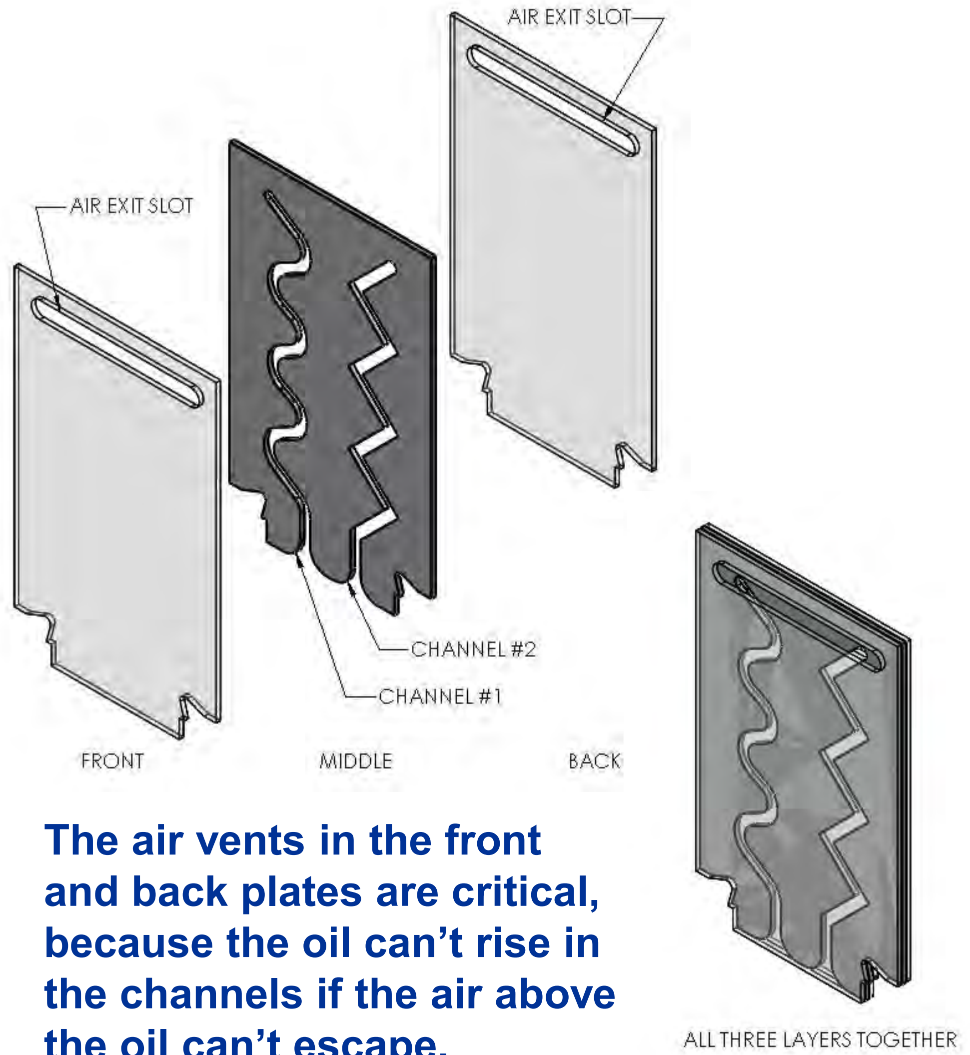


Example test cell design (from the design challenge's handbook and tutorial).

What is it? How does it work? - 2

- **The students design their test cell's center (black) layer, which must include at least two channels to allow a variable to be tested.**
- **The test cell is manufactured by Portland State University (PSU) using the CAD drawing and a computer-controlled laser cutter.**





The air vents in the front and back plates are critical, because the oil can't rise in the channels if the air above the oil can't escape.

Anatomy of a sample test cell (from the design challenge's handbook and tutorial).

What is it? How does it work? - 3

- The experiment is conducted in PSU's Dryden Drop Tower in which falls 22 meters (73 feet) and experiences 2.1 seconds of microgravity
- The experiment is filmed while it falls down the shaft, and the resulting video and still images are posted online.
- The students can analyze and report on their results, e.g., in a classroom presentation or science fair.

Portland State UNIVERSITY

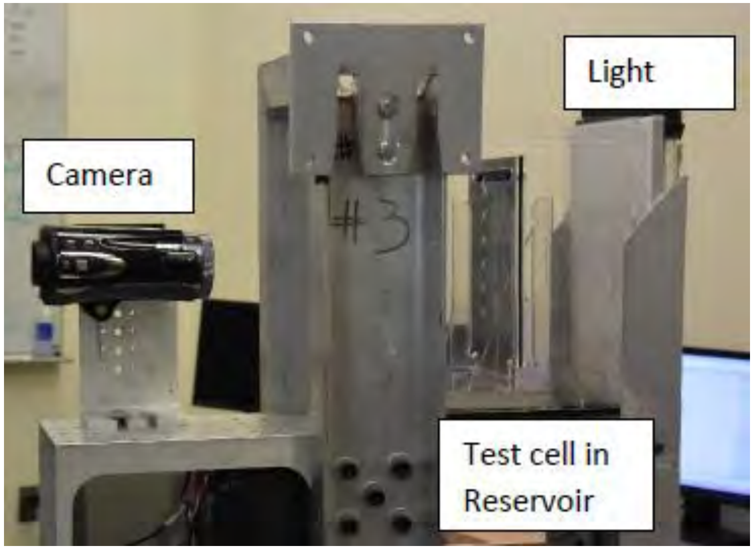
What is a drop tower?

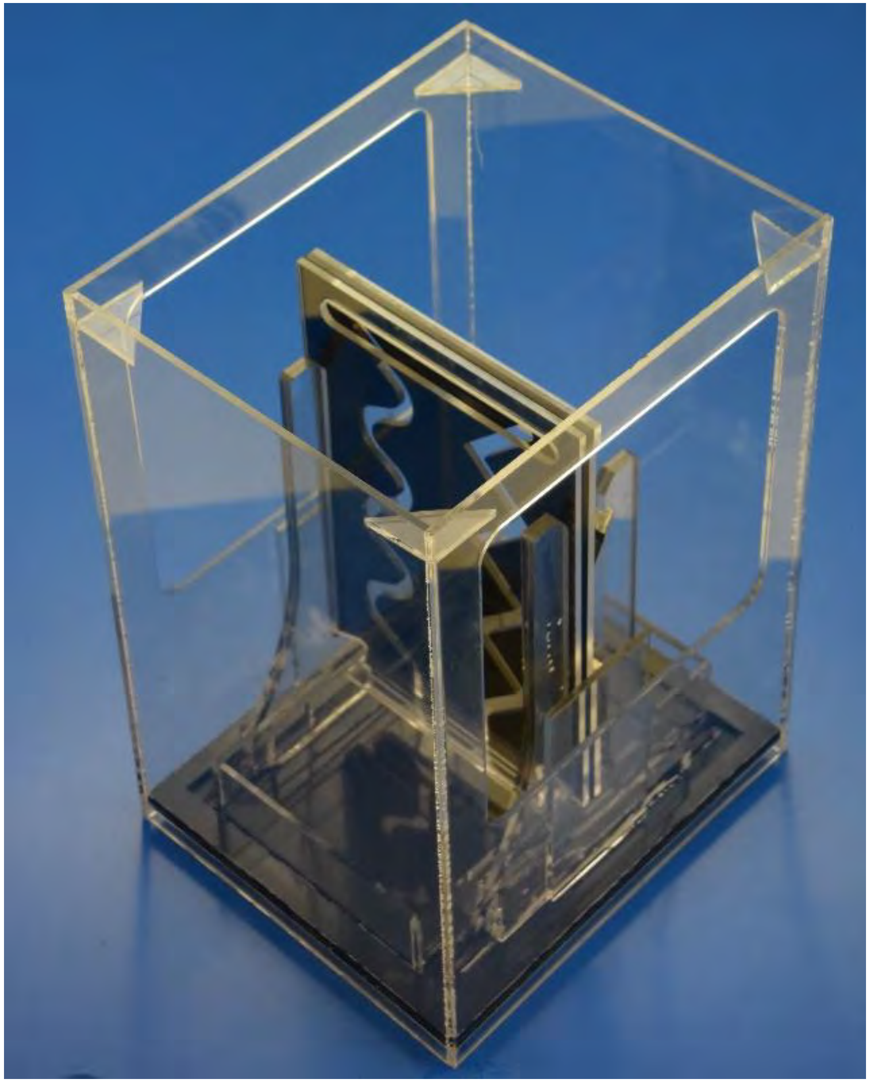
- Drop towers are ground-based facilities for conducting experiments in apparent near weightlessness, i.e., microgravity.
- When an experiment falls down a drop tower, it behaves as if gravity has nearly vanished (of course neglecting the fall).
  - Our sensation of gravity and weight comes from a resistance to its pull, for example because of the floor holding us up.
  - While freely falling, we feel weightless and that is the basis for many amusement park rides.
- Freely falling objects seem to be weight-less because all objects fall at the same acceleration (regardless of their mass) unless acted upon by another force.

Dryden Drop Tower at Portland State University (Portland, Oregon)

What is dropped?

- **The test cell is mounted with its bottom edge in a reservoir of thin, runny silicon oil within an open plastic box; see right.**
- **The plastic box is mounted on a test rig between a back light and a high-speed, high-resolution video camera; see below.**

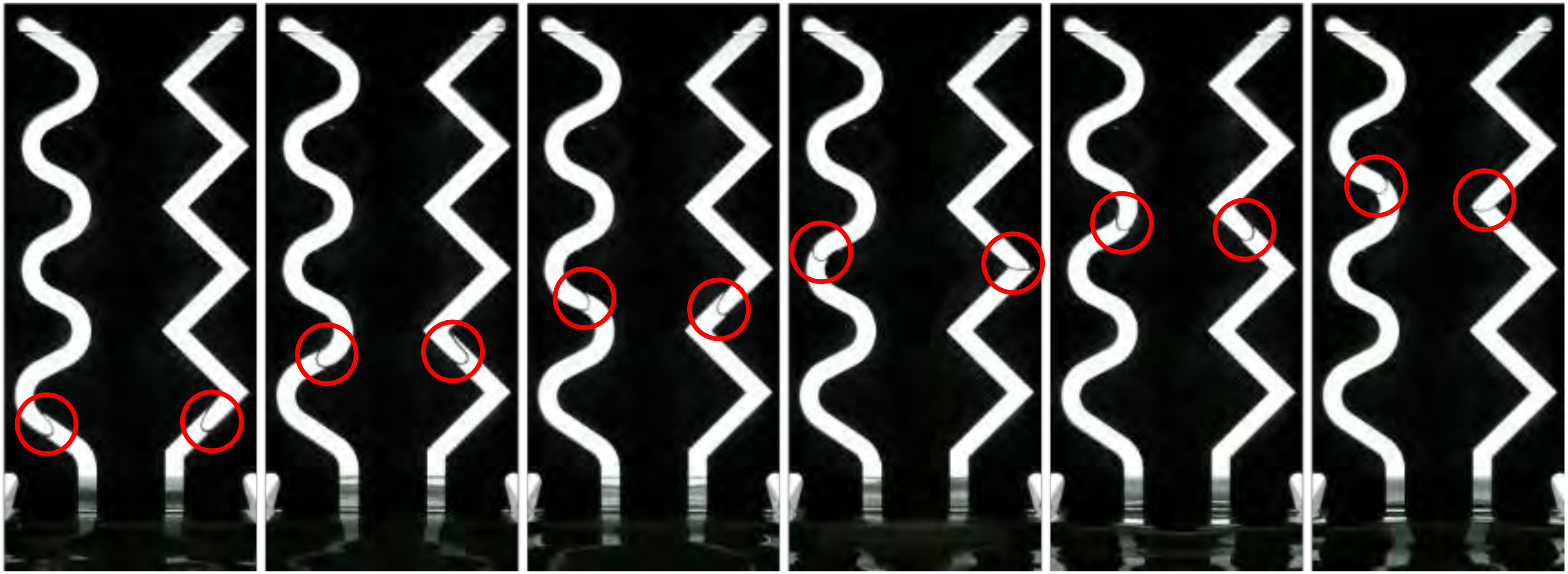




Drop rig (left) and test cell mounted in reservoir (right).

What happens during the drop?

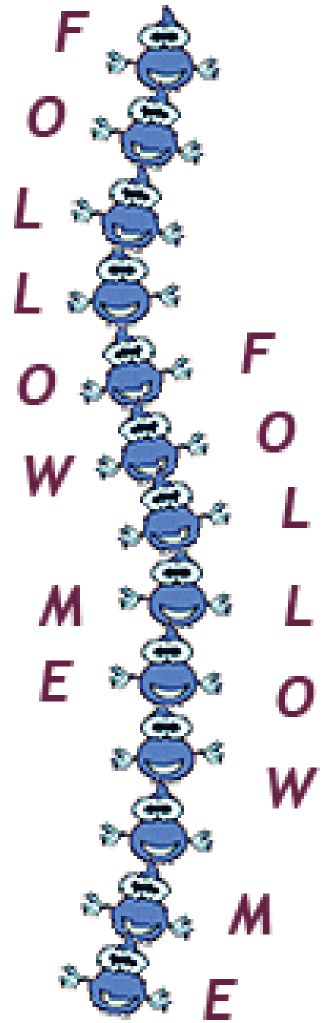
- **In microgravity, capillary action causes the oil to rise from its reservoir through the channels in the test cell.**
- **In each channel, the top of the oil can be seen by the upward curved meniscus, i.e., the interface between the oil and air.**
- **A sequence of images is shown below, in which the oil can be seen to rise within the two zig-zagging channels.**



Sequence of images from the example experiment shown in the design challenge handbook.

Why does the oil rise?

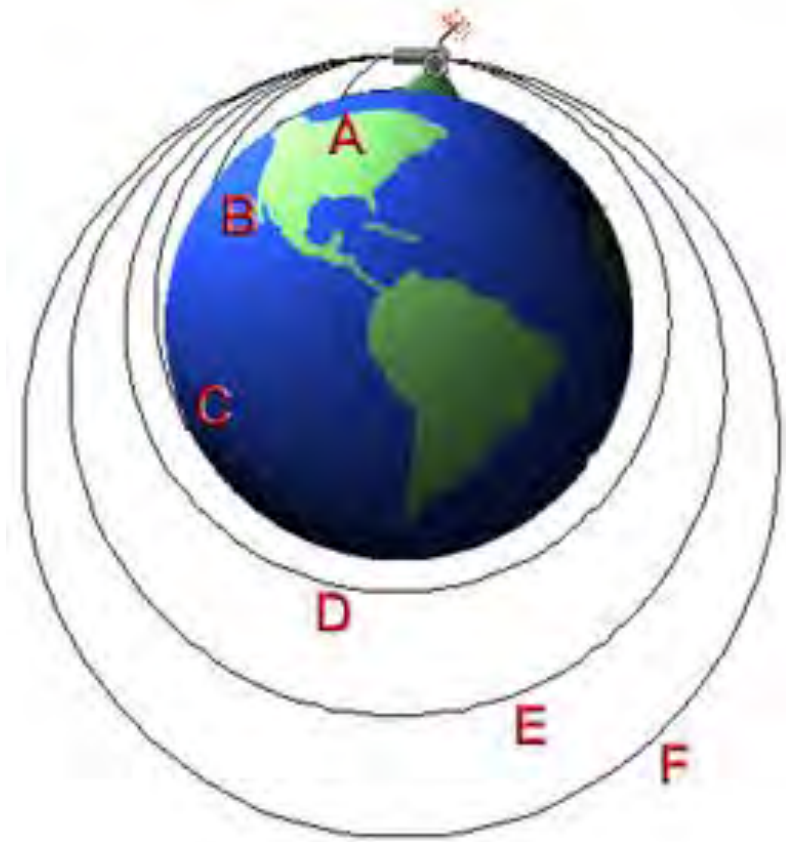
- Capillary action is the motion of a liquid due to the forces of adhesion, cohesion, and surface tension.
  - Adhesion: attraction of the liquid molecules to solid surfaces
  - Cohesion: attraction of the liquid molecules to each other
  - Surface tension: strong cohesion at a liquid's surface that keeps the surface intact
- Capillary action occurs when the adhesion to the walls is stronger than the cohesive forces between the liquid molecules.
- Normally, the height to which capillary action will raise liquid in a tube is limited by gravity.
- In microgravity, the liquid can rise without limit.



MICROGRAVITY

How does it work on ISS?

- **Astronauts & experiments do not float or experience microgravity because they are in space!**
- **They float and experience microgravity because the space station and everything in it are freely falling, like the drop tower experiments, but in a curved path around Earth (i.e., path D in the image at the right)**
  - **at ~28,000 km/hour (17,500 mph)**
- **This happens even though ISS is so close to the Earth that the gravity is only about 10% less than that on the planet surface.**



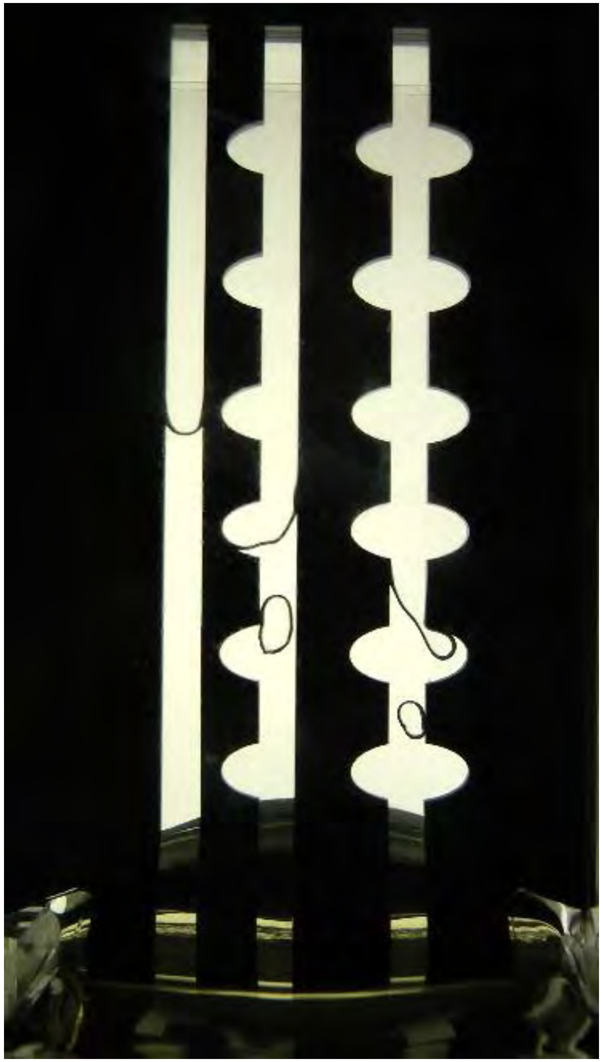
Why is capillary flow of interest?

- **On Earth, liquids naturally flow downward because of gravity and equipment is built to take advantage of that factor.**
  - **For example, cars draw gasoline from the bottom of the tank.**
- **In microgravity, liquids naturally flow because of capillary action. Therefore, capillary flow is important for a variety of liquid systems on spacecraft, including for example**
  - **propellant systems,**
  - **water collection, recycling, and processing,**
  - **thermal control systems,**
  - **materials processing.**

Astronaut Doug Wheelock working on a Sabatier reactor which produces water on ISS.

Who is eligible to participate?

- **Individuals or teams**
- **Grades 8-12 or multi-age teams (e.g., science clubs, Scout groups) which include at least one student in grades 8-12**
  - **Youth are free to get help from adults, e.g., with the CAD drawing.**
- **Students from the United States only, including all fifty states, the District of Columbia, Puerto Rico, American Samoa, Guam, the Northern Mariana Islands, and the U.S. Virgin Islands.**
  - **But U.S. citizenship is not required.**



Example test cell from Niles Middle School (Niles, OH).

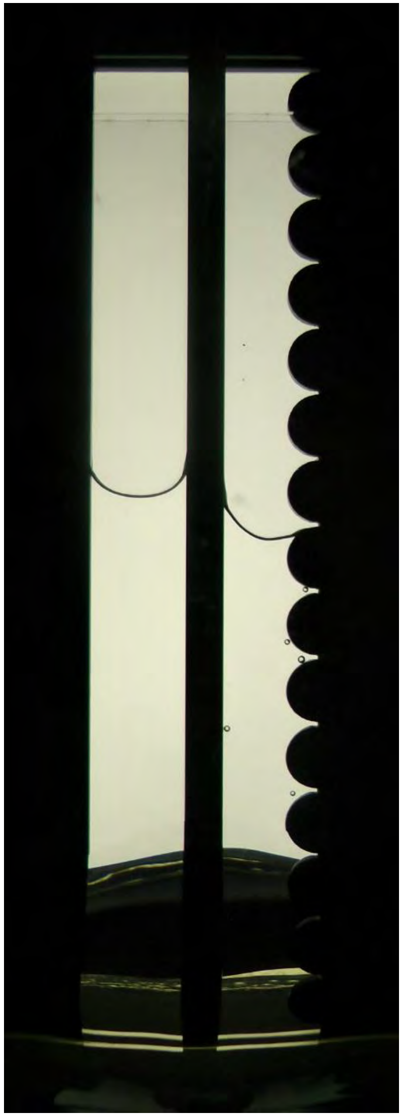
Why should students participate?

- **To use and learn about computer technology such as CAD,**
  - **where Boy Scouts might be able to use the CAD drawing towards the *Drafting* merit badge.**
- **To participate in research related to space station science.**
- **For a noteworthy accomplishment to include in college applications, i.e., selection by NASA in a nation-wide design challenge!**
- **To become inspired to pursue STEM careers.**

Astronaut Jeff Williams conducting the Capillary Flow Experiment (CFE)

Some Student Comments - 1

- CELERE was an interesting project that tested creativity as well as the ability to problem solve. It was a good experience to be working with NASA and to be doing official reports and entry forms in order to become a part of this. It was also interesting to see and analyze the results of the projects we came up with so that we could test if our hypothesis is different from the results.
- CELERE allowed students to apply concepts to a real life-situation as opposed to an irrelevant story problem. We were able to utilize and adapt the steps to the scientific method that we've memorized to an actual experiment.
- CELERE made me think creatively and look for the best solution. It also required dedication and teamwork. This project was interesting and has practical application, which is nice to see in a project. CELERE also is a project that I will be knowledgeable about for the future and will look good on a college application.



Example 2013 experiment from Columbus High School (Columbus, GA).

Some Student Comments - 2

- CELERE allowed students to be apart of a real experiment. Since I want to go [into] the science track in college and beyond, it allows me to see what I will be doing with the rest of my life.
- I was able to essentially construct my own experiment and conduct my own research. I liked how students were able to get involved in a NASA program to help build up college resumes.
- CELERE was very exciting because we were able to conduct a real-life experiment with NASA. I enjoyed coming up with our own design for them to test. Also, looking at the final video from NASA of our experiment was very rewarding.

- And some comments from a teacher:
  - Offered unique opportunity for depth research and experimental design and analysis
  - My students learned so much about the nature of experimentation that is more authentic, novel, and “out of this world”
  - I also learned that they were very excited to "own" an experiment.

How many entries are selected?

- **Thus far, 100% of the received submissions have been selected for fabrication and testing … because of the limited number of entries received.**
- **Currently, our goal is to select ~30 entries per month for testing in February, March, and April for a total of 100 experiments.**
  - **Each organization, e.g., school, can currently submit up to 15 entries total for the 3 months.**
  - **Each student can submit up to 1 entry total for the 3 months.**
- **The odds of selection diminish from month to month, i.e., where the February odds are best and April odds are worst.**

What is the basis for selection?

- **Selection is based on adherence to the experiment and drawing requirements listed in the handbook. For example, the drawing requirements are currently:**
  - **Cut lines must be continuous (without gaps),**
  - **cut lines must not cross themselves or each other,**
  - **cut lines must not pass into the border zone, marked with the diagonal pattern,**
  - **channel cuts must begin at the test cell base, pass into the green-outlined vent zone, and return to the test cell base,**
  - **channels must be at least 3 mm apart, and**
  - **nothing (incl. text) can be outside of the boundaries of the test cell.**
- **A program goal is to reach a broad diversity of participation, e.g., from every U.S. state and territory.**

CAD drawing template for the test cell design.

What are the other requirements?

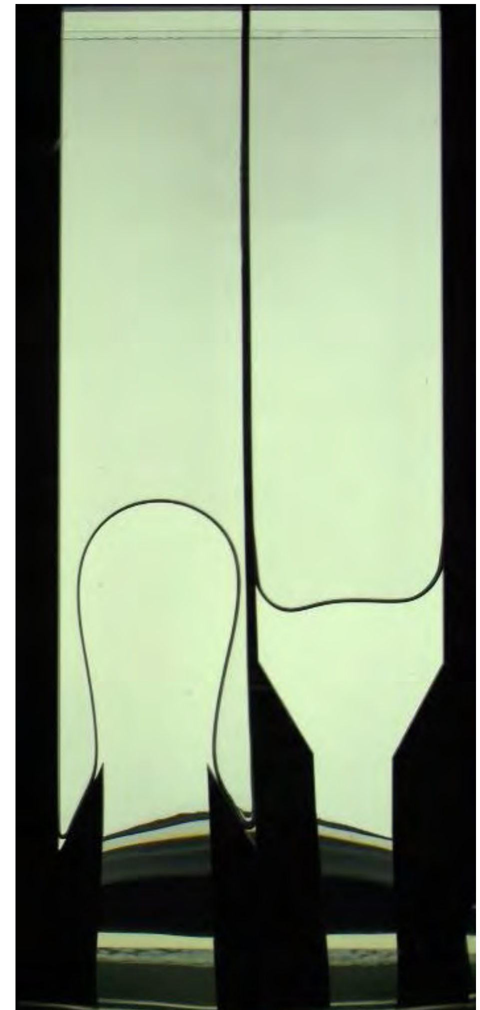
- **The experiment requirements are currently as follows:**
  - **The experiment must have a research question that is specific to the test cell's channels,**
  - **the research question must address the effect of the channel shape and/or size on the capillary flow,**
  - **the experiment must include only one test cell (and thus only one drawing),**
  - **the test cell must have at least 2 channels,**
  - **the channels should ideally differ in a single way,**
  - **the variation between the channels must address the research question,**
  - **the experiment must differ from the past CELERE experiments depicted in the handbook's appendix, and**
  - **the drawing and entry files must be named as:**

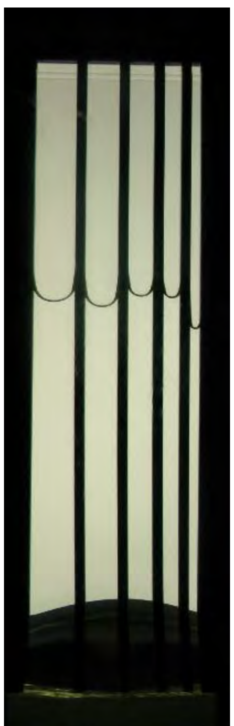
    CELERE_2015_<StateInitials>_<OrgAbbrev>_<AdvisorLastName>_<ParticipantAbbrev>

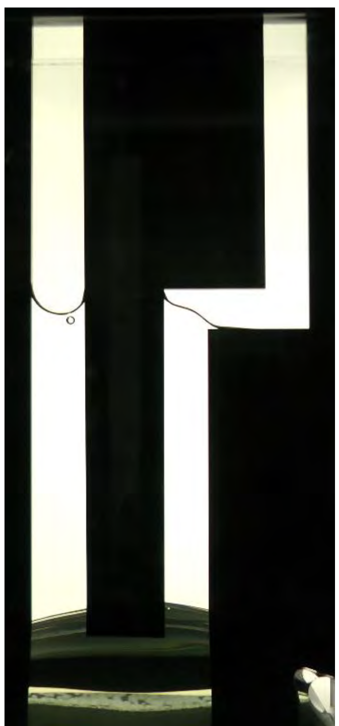
    where the drawing is a dwg file and the entry file is in a pdf or doc format.

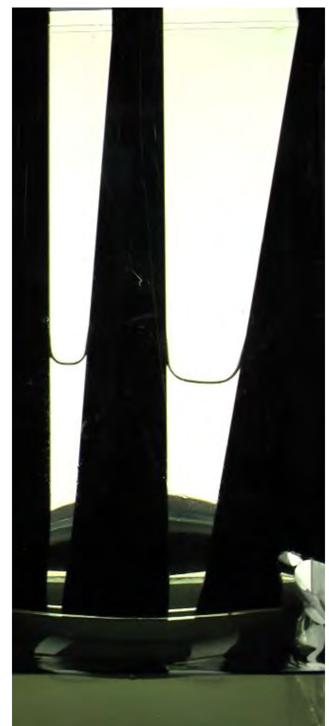
What has been tested in the past? - 1

- **Past experiments have included studies of the effects of:**
  1. **channel width** - ***where this type is now discouraged!***
  2. **channel path**
  3. **channel inlet**
  4. **uniform expansion and contraction**
  5. **abrupt expansion and contraction**





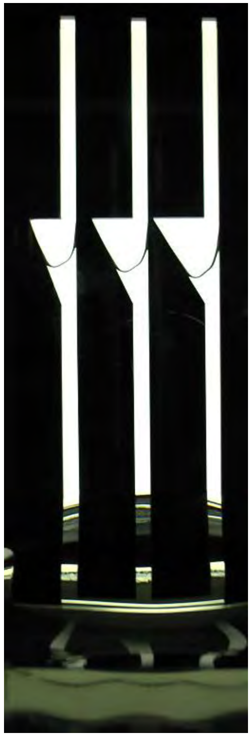


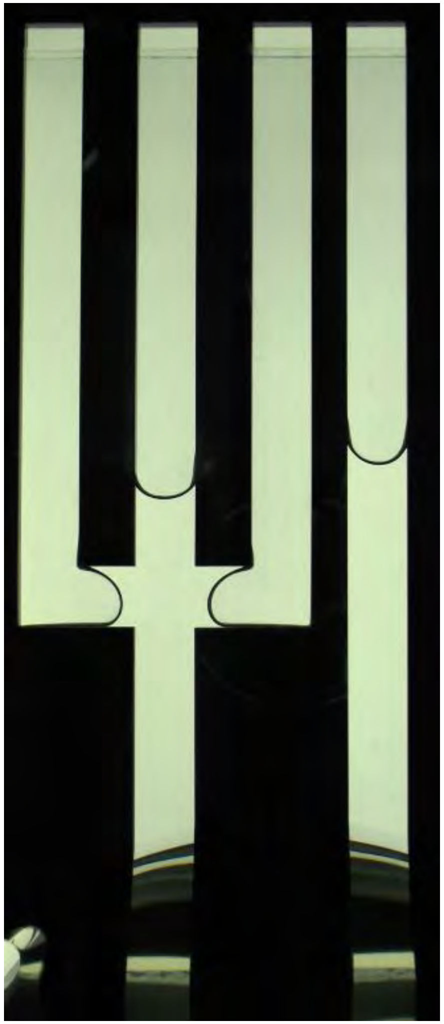
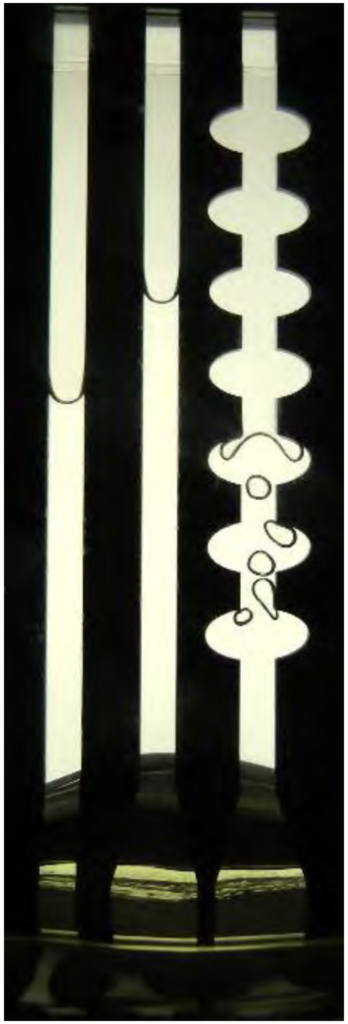


Example experiments from 2013 and 2014.

What has been tested in the past? - 2

- **Past experiments have also included studies of the effects of:**
  6. **cavities and protrusions**
  7. **channel roughness**
  8. **channel branching**
  9. **combined effects**



Example experiments from 2014.

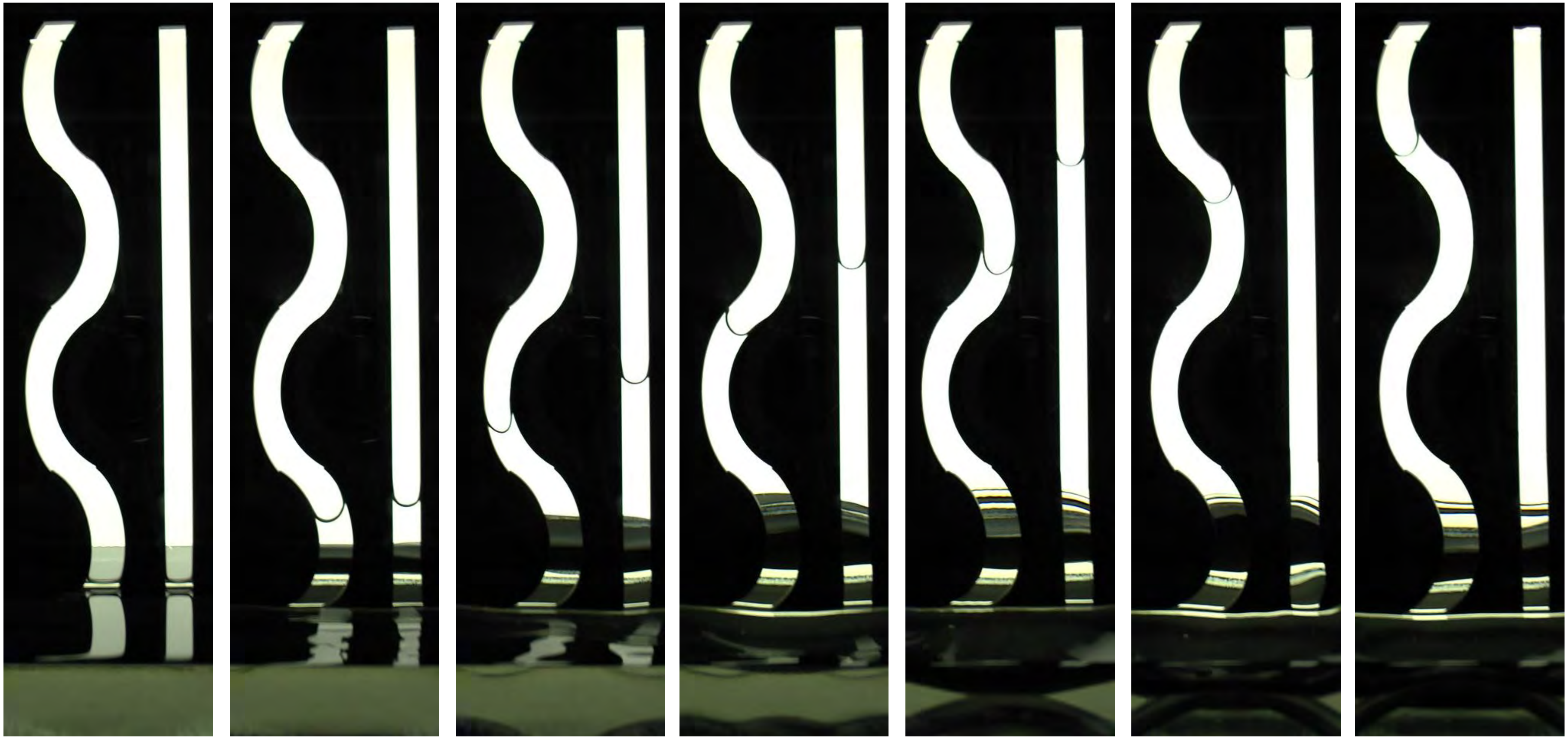
What's the effect of the channel width?

- **For the experiment below (with straight-walled channels), the oil initially rises more quickly in the narrow channels; see the second image.**
- **But the rising oil slows down (i.e., decelerates) during the drop and that slowing is more dramatic in the narrow channels.**
- **The channel in which the oil first reaches the top is based on a balance of those behaviors … and the oil properties & drop duration.**

Sequence of images from a 2013 experiment which are 1/3 second apart.

What's the effect of the path?

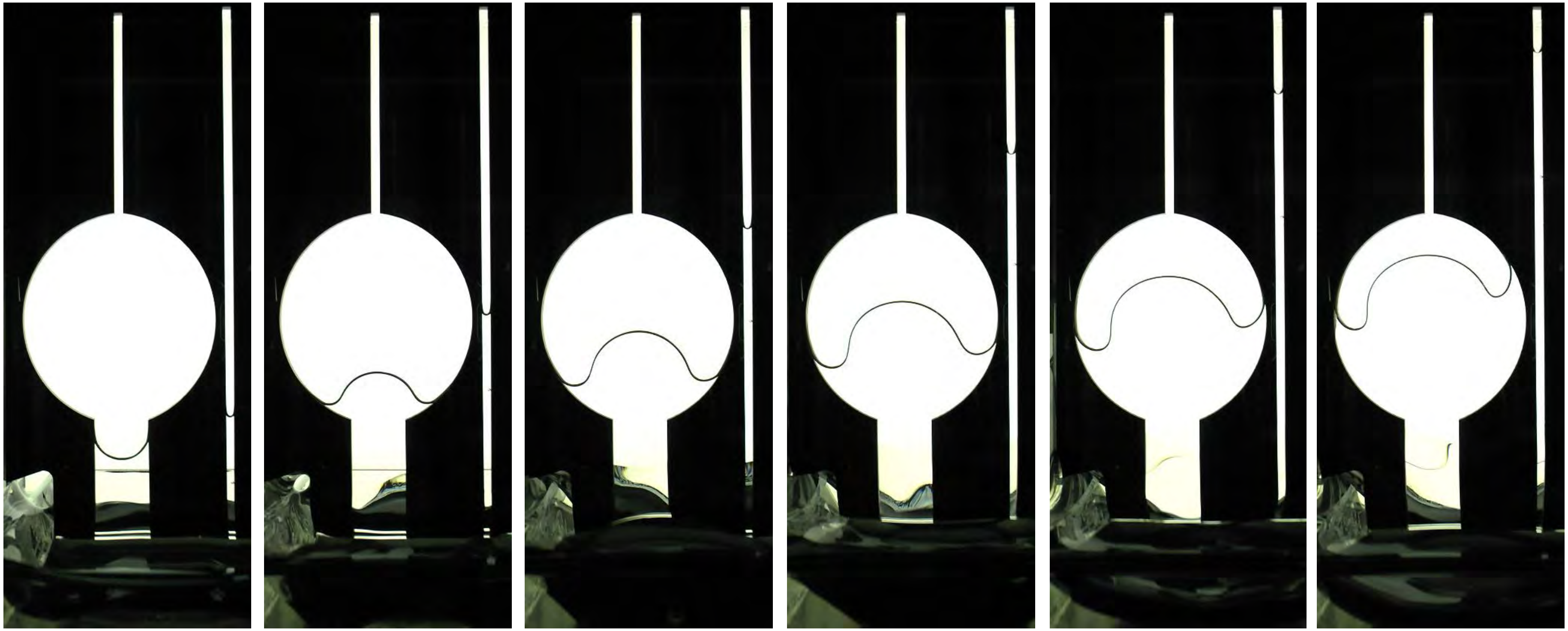
- **In the experiment below, the oil in the curving channel rises more slowly towards the top … although it has a longer path to reach it.**



Sequence of images from a 2014 experiment which are 1/3 second apart.

What about an abrupt expansion?

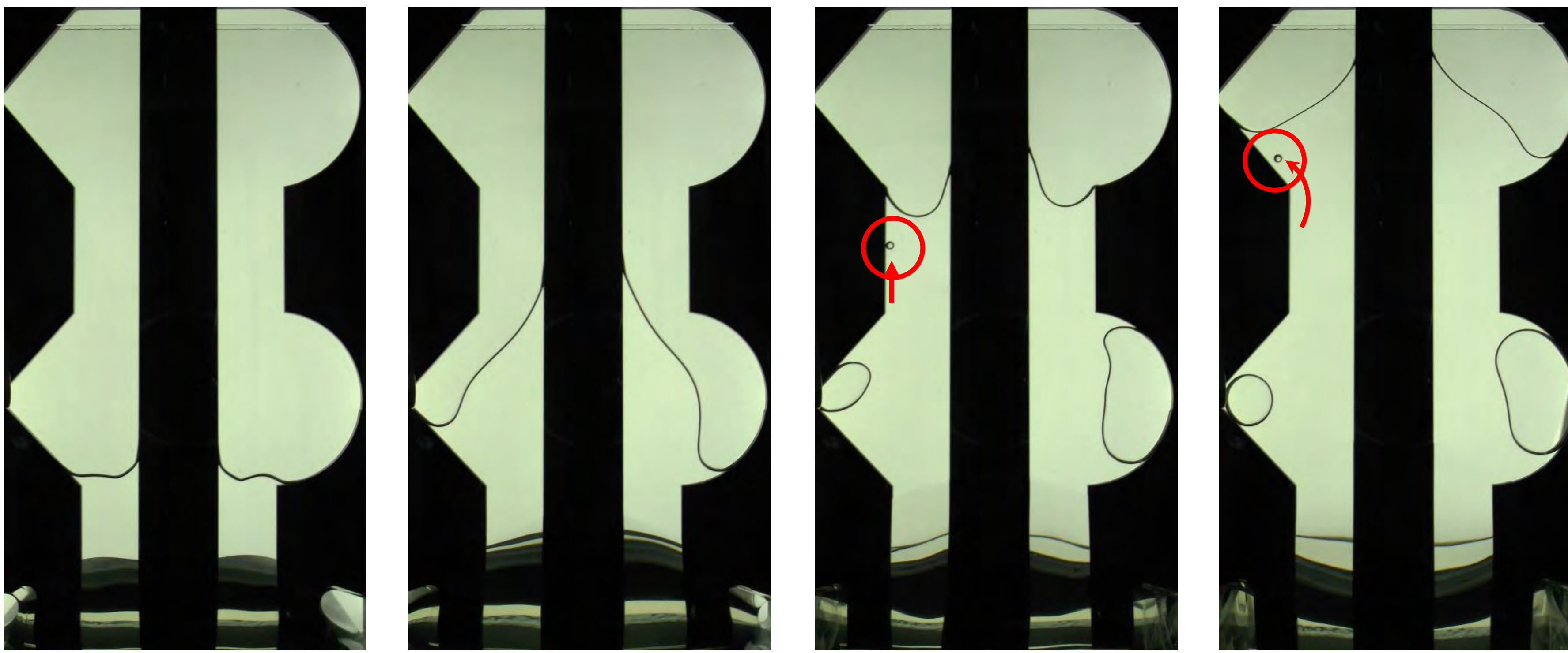
- **In the experiment below, the oil in the left channel continues to rise straight up, even where it is not touching the channel's side walls.**
- **However, capillary action is still at work. The oil climbs in the middle because of its adhesion to the clear front and back plates.**



Sequence of images from a 2014 experiment which are ~1/3 second apart.

How do cavities affect the motion?

- In the experiment below, it can be seen that the oil's upward climb is slowed by the cavities.
- It can also be seen that large bubbles (of air) have been trapped, at least temporarily, in the lower cavities.
- But a small bubble does escape the lower cavity in the left channel and follows the oil's motion into the next cavity and along the channel wall.



Sequence of images from a 2014 experiment which are 1/2 second apart.

Any ideas for new experiments?

- The design challenge is intended for open-ended, curiosity-driven research, but participants are free to choose their own design challenge. Some suggestions include:
  - Make the oil rise as quickly as possible in a channel, for example, by variation of the inlet section.
    - Thus far, there has been very few CELERE investigations of inlet effects.
  - Make the flow as bubbly as possible, i.e., where the bubbles are mixed with the oil and not just stuck in cavities.
  - Make a ‘fountain,’ where the oil doesn’t touch the left or right walls of the channel, rise as far as possible.
    - To be clear, the oil rises because of its contact with the clear front and back layers, so it isn’t unconfined.
  - Advance what can be learned from past CELERE experiments by taking ‘a next step.’ Choose an interesting past experiment and design a related experiment that can bring new understanding.
    - Past experiments are described in the handbook.
  - Try something completely new!

How can CELERE be implemented?

- Extra credit project
- Science fair project
- Independent project, where school involvement is not required, but promotion of the challenge would be appreciated!
- Assigned homework, where this approach has been taken

Face the Challenge!

- ***Microgravity Man* wants you** **… to challenge your students to participate and design their own microgravity experiments!**

- **For more information about this International Space Station design challenge, see** **http://spaceflightsystems.grc.nasa.gov/CELERE/** **or contact: celere@lists.nasa.gov.**